NASA-CR-54113

NASA

MATERIALS FOR POTASSIUM LUBRICATED JOURNAL BEARINGS

Quarterly Progress Report No. 4
For Quarter Ending April 22, 1964

EDITED BY R. G. FRANK

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-2534

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI 15, OHIO

NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

A.) Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B.) Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with NASA, or his employment with such contractor.

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D.C.
Attention: AFSS-A

MATERIALS FOR POTASSIUM LUBRICATED JOURNAL BEARINGS

QUARTERLY PROGRESS REPORT NO. 4

Covering the Period
January 22, 1964 to April 22, 1964

edited by

R. G. Frank
Program Manager

approved by

J. W. Semmel, Jr.
Manager, Materials and Processes

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-2534

Technical Management
NASA - Lewis Research Center
R. L. Davies

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO, 45215

FOREWORD

The work described herein is being performed by the General Electric Company under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2534. Its purpose, as outlined in the contract, is to evaluate materials suitable for potassium lubricated journal bearing and shaft combinations for use in space system turbogenerators and, ultimately, to recommend those materials most appropriate for such employment.

R. G. Frank, Manager, Physical Metallurgy, Materials and Processes, is administering the program for the General Electric Company. L. B. Engel, Jr., D. N. Miketta, T. F. Lyon, and W. H. Hendrixson are directing the program investigations. The design for the friction and wear tester is being executed by H. H. Ernst and B. L. Moor.

R. L. Davies of the National Aeronautics and Space Administration is the technical manager for this study.

CONTENTS

ILLUSTRATIONS

TABLES

I. INTRODUCTION

The program reviewed in this fourth quarterly report, covering activities from January 22, 1964 to April 22, 1964, is performed under the sponsorship of the National Aeronautics and Space Administration. Its purpose is to evaluate materials suitable for potassium lubricated journal bearing and shaft applications in space system turbogenerators operating over a $400^{\circ}F$ to $1600^{\circ}F$ temperature range. The critical role of bearings in such systems demands the maximum reliability attainable within today's state-of-the-art. Achieving this reliability requires an interdisciplinary approach employing the best mechanical designs of journal bearings combined with the selection of the optimum materials to serve as the structural members. Satisfying this latter requirement constitutes the aim of this program.

A number of investigators have conducted studies in this field and their contributions have advanced the state-of-the-art considerably [Section VIII, Ref. 1]. Although their work is significant, there are no common criteria for a comparison of the existing data. Therefore, establishing a unified approach to the development and evaluation of materials for potassium lubricated bearing application is deemed essential. The program involves a comprehensive investigation of material properties adjudged requisite to reliable journal bearing operation in the proposed environment. This includes: 1) corrosion testing of individual materials and potential bearing couples in potassium liquid and vapor, 2) determination of hot hardness, hot compressive strength, modulus of elasticity, thermal expansion and dimensional stability characteristics, 3) wetting tests by potassium, and 4) friction and wear measurements of selected bearing couples in high vacuum and in liquid potassium.

Applying a compilation of existing data on available materials, candidate materials have been selected in cooperation with the cognizant NASA technical manager. The materials reviewed fall into four broad categories:

- Superalloys and refractory alloys with and without surface treatment.
- Commercial metal bonded carbides.
- Refractory compounds such as stable oxides, carbides, borides and nitrides.
- Cermets based on the refractory metals and stable carbides.

Each material is being procured from appropriate suppliers to mutually acceptable specifications and subsequently will be subjected to chemical, physical and metallurgical analyses to document its characteristics before utilization in the program. After the documentation of processes and properties, the candidate materials will undergo corrosion, dimensional stability, thermal expansion, compression and hot hardness testing. Considering the bearing material requirements and the preliminary information obtained on materials subjected to both potassium and non-potassium testing, a number of materials combinations will be selected in cooperation with and subject to the approval of the NASA technical manager. Potassium corrosion and wetting tests and friction and wear measurements in high vacuum and liquid potassium will then proceed with these combinations.

The ultimate product of this program will be a recommendation, substantiated with complete documentation, of the material or materials which have the greatest potential for use in alkali metal journal bearings in high speed, high temperature, rotating machinery for space applications. Hopefully, the results will indicate the future course of alloy or material development specifically designed for alkali metal lubricated journal bearing and shaft combinations.

II. SUMMARY

During the fourth quarter of this program, the topics abstracted below were covered and the results are interpretatively presented in this report.

Corrosion and dimensional stability test specimens for 13 of the 14 candidate materials were ordered and procurement of the hot hardness, thermal expansion and compression specimens was initiated.

One-hundred pounds of potassium were received from MSAR Corporation of which 24.5 pounds were transferred to a modified 25-pound capacity shipping container and outgassed at 315°F to 450°F in preparation for repurification at General Electric. The oxygen and metallic impurity content in the as-received potassium showed the potassium to be of extremely high purity.

Fabrication of all major components of the isothermal capsule test facilities and the dimensional stability test facilities was completed. One of the 5 isothermal capsule test facilities was assembled and instrumented with 6 Cb-1Zr alloy test capsules containing potassium and the high vacuum chamber was evacuated in preparation for the checkout tests.

The Chevenard dilatometer was modified to enable the instrument to be evacuated and backfilled with high purity helium.

Several design changes were incorporated in the liquid potassium friction and wear tester. The design of the potassium immersion heater was changed from a flat disc type heater to a fire-rod design based on Watlow Electric's standard fire-rod heater element. Bakeout heaters and radiation shielding were added outside of the inner stainless steel jacket which surrounds the Cb-1Zr alloy container. Cooling coils were added to the outer surface of the shaft housing between the main bearings. The thickness of the INCO 718 nonmagnetic diaphragm between the magnets of the magnetic clutch was increased from 0.016 inch to 0.026 inch to provide a suitable safety factor in the event of accidental pressure loss on one side of the diaphragm.

A heat transfer analysis was initiated for the final design of the liquid potassium test rig. Critical shaft speed calculations for the final design show a ratio of 2.03 between the first critical and the maximum test speed (Ncr/4800 rpm).

The facility requirements for the liquid potassium friction and wear tester have been finalized and drawings are being prepared for submission to the NASA technical manager for review and approval. The major items of the facility include: 1) potassium and inert gas purification systems, 2) auxiliary heating and cooling equipment, 3) environment chamber for enclosing the tester, 4) facility for transferring the potassium to and from the tester and 5) instrumentation.

Technical review meetings were held with the NASA technical manager on February 19, 1964, and April 8, 9, 10, 1964.

III. MATERIALS PROCUREMENT

Test Facility Raw Stock

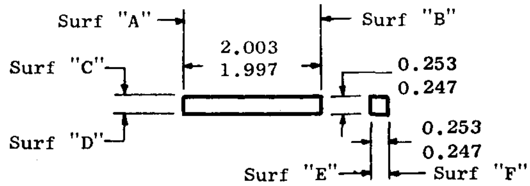
Thirty dimensional stability test specimens (Figure 1, Part 2) were ordered, received and machined during the report period from a 1.260-inch diameter x 48-inch long bar of unalloyed molybdenum. These specimens will be utilized to checkout the thermal characteristics of the dimensional stability test facility and to establish testing techniques. The material, procurred from the Universal-Cyclops Steel Corporation, Bridgeville, Pennsylvania, was produced from heat number KDM 1206A. The certificate of test certified to the following chemical analysis:

	Heat No. KDM 1206A	Specified Maximums
Carbon	330 ppm	400 ppm
Oxygen	15 ppm	15 ppm
Nitrogen	7 ppm	20 ppm
Hydrogen	1 ppm	5 ppm

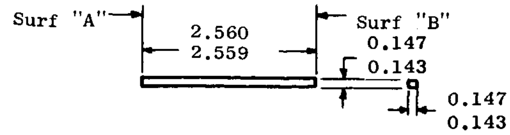
Bearing Materials

Table I summarizes the procurement status of the corrosion and dimensional stability test specimens of the materials being investigated in this program. The following quantities of finished specimens as shown in Figure 1 were ordered.

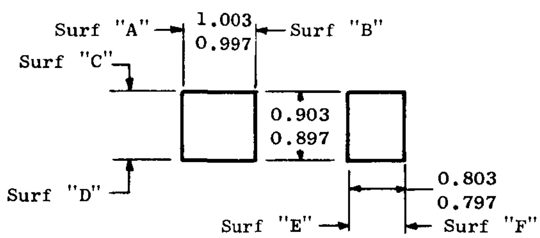
Specimen	Drawing and Part No.	Quantity
Corrosion	SK56131-232, Part 1	16
Dimensional Stability	SK56131-232, Part 2	10



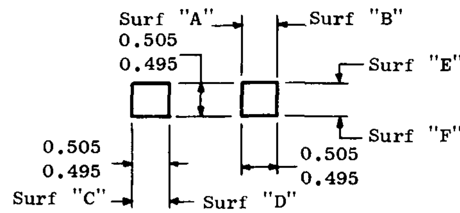
1. Corrosion Test Specimen
   a. 10-15 Microinch Finish All Over
   b. Surfaces A&B, C&D, E&F to be Flat & Parallel Within 0.001 FIR
   c. Delineated Right Angles are $90^{\circ} \pm 30$ Min.



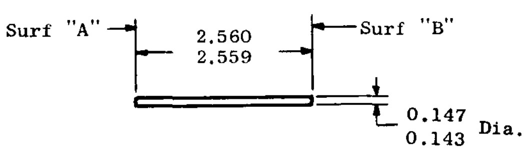
3-B. Thermal Expansion Test Specimen
   a. 10-15 Microinch Finish Surfaces A&B, All Other Surfaces 63 Microinch Finish
   b. Surfaces A&B to be Parallel & Flat Within 0.001 FIR
   c. Delineated Right Angles to be $90^{\circ} \pm 30$ Min.



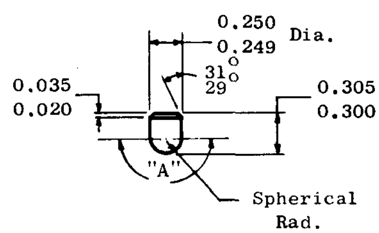
2. Dimensional Stability Test Specimen
   a. 10-15 Microinch Finish All Over
   b. Surfaces A&B, C&D, E&F, to be Flat & Parallel Within 0.002 FIR
   c. Delineated Right Angles Are $90^{\circ} \pm 15$ Min.



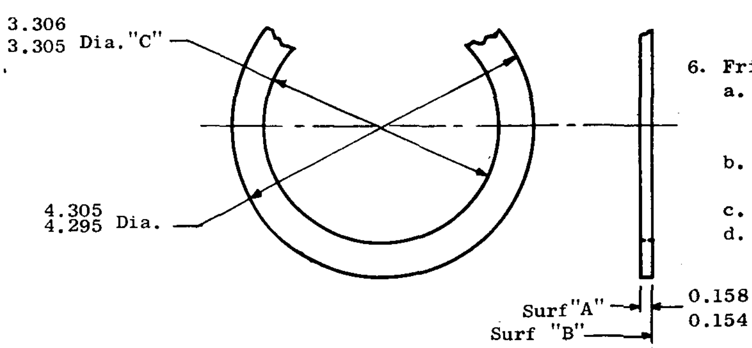
4. Hot Hardness Test Specimen
   a. 10 Microinch Finish Surfaces A&B
   b. All Other Surfaces 63 Microinch Finish Surfaces C&D, E&F
   c. Surfaces A&B, C&D, E&F to be Flat & Parallel Within 0.001 FIR
   d. Delineated Right Angles are $90^{\circ} \pm$ Min.



3-A. Thermal Expansion Test Specimen
   a. 10-15 Microinch Finish Surfaces A&B, All Other Surfaces 63 Microinch Finish
   b. Surfaces A&B to be Parallel & Flat Within 0.001 FIR
   c. Delineated Right Angles Are $90^{\circ} \pm 30$ Min.



5. Friction & Wear Test Specimen
   a. Microinch Finish at Area "A" to be Specified - All Other Surfaces 63 Microinch Finish



6. Friction & Wear Test Specimen
   a. Microinch Finish Surfaces "A"&"B" to be Specified - All Other Surfaces 63 Micro-Inch Finish
   b. Surfaces A&B to be Parallel & Flat Within 0.001 FIR
   c. Delineated Right Angles Are $90^{\circ} \pm 30$ Min.
   d. Dia "C" to be Square With Surfaces "A" & "B" Within 0.002 FIR

Figure 1. Dimensions of Test Specimens to be Used for Corrosion, Dimensional Stability, Hot Hardness, Thermal Expansion, and Friction and Wear Test Programs.

TABLE I: PROCUREMENT STATUS OF THE CANDIDATE BEARING MATERIALS

Item	Material	Specification	Purchase Order No.	Vendor	Promised Delivery
1	Lucalox	SPPS-29T(1)	037-121835	GE - Lamp Metals	4-30-64
2	Star J	SPPS-18T(1)	037-121822	Stellite Division, UCC	4-27-64
3	Tungsten	SPPS-40T(1)	037-122059	Universal-Cyclops Steel Corporation	Delivered to Machining Vendor.(2)
4	TZM	SPPS-15(1)	037-121885	American Metals Climax Company	Delivered to Machining Vendor.(2)
5	Carboloy 907	SPPS-23T(1)	037-121815	GE - Metallurgical Products Department	4-24-64
6	Carboloy 999	SPPS-24T(1)	037-121815	GE - Metallurgical Products Department	4-24-64
7	TiB_2	SPPS-37T(1)	037-121867	Norton Company	6-29-64
8	ZrO_2	SPPS-31T(1)	037-121868	Zirconium Corporation	4-27-64
9	K601	SPPS-25T(1)	037-122216	Kennametal, Inc.	5-29-64
10	TiC	SPPS-27T(1)	037-121842	Kennametal, Inc.	5-29-64
11	TiC+5%W	SPPS-33T(1)	037-121842	Kennametal, Inc.	5-29-64
12	TiC+10%Mo	SPPS-34T(1)	037-121842	Kennametal, Inc.	5-29-64
13	TiC+10%Cb	SPPS-35T(1)	037-121842	Kennametal, Inc.	5-29-64
14	Grade 7178	SPPS-36T	(3)	Kennametal, Inc.	-

TABLE I (Cont'd)

Item	Material	Specification	Purchase Order No.	Vendor	Promised Delivery
15	Vasco Hypercut[(4)]	P.O.	037-121889	Vanadium Alloys	On Hand
16	Iron[(4)]	AMS 7706	037-121887	Steel Sales	On Hand

(1) Modifications to the original specifications per mutual agreement by purchaser and vendors to expedite procurement without detriment to the material.

(2) Machining by Dawson Carbide Industries, Detroit, Michigan, on Purchase Order 037-124116 with promised delivery of 5-1-64.

(3) On inquiry as of 4-22-64.

(4) Ordered prior to deletion from the selected list of materials.

Provisions were also made to hold sufficient material of the same lot of powder to produce the following quantities of bearing test specimens (Figure 1) at a later date under option of the General Electric Company:

Specimen	Drawing and Part No.	Quantity
Corrosion	SK56131-232, Part 1	60
Thermal Expansion	SK56131-232, Part 3-A	3
Hot Hardness	SK56131-232, Part 4	3
Rider	SK56131-232, Part 5	180
Plate	SK56131-232, Part 6	70
Compression	SK56131-401, Part 1	25

The wrought materials, purchased as bar stock, will be fabricated by a separate machining vendor into finished test specimens. The 16 corrosion specimens will be machined from 0.437-inch diameter x 48-inch long bar stock and the 10 dimensional stability specimens from 1.250-inch diameter x 36-inch long bar. Because of the reproducibility inherent in the wrought materials, it was considered technically and economically justifiable not to hold additional wrought materials from the same heat for possible future testing.

The TZM molybdenum alloy and the unalloyed tungsten, received at General Electric near the end of the quarter, were shipped immediately to Dawson Carbide Industries, Detroit, Michigan, for machining into finished specimens.

Final inquiries for the procurement of the thermal expansion, hot hardness and compression test specimens were forwarded to the vendors in April. Again, the wrought materials, TZM and tungsten, will be procured as bar stock. The quantity of specimens and the size of the bar stock required are:

		Barstock Dimensions	
Specimen	Number of Specimens	Diameter, Inches	Length, Inches
Thermal Expansion	3	0.187	12
Hot Hardness	3	0.750	12
Compression	10	1.560	36

A similar number of finished specimens will be obtained for the powder metallurgy materials.

Potassium

One-hundred pounds of potassium were ordered from the Mine, Safety and Appliance Research Corporation and received in shipping container No. D-80. The chemical analysis of the potassium, furnished by MSAR, and obtained by spectrographic techniques at NUMEC, is listed in Table II. The oxygen, analyzed by the mercury amalgamation method at MSAR, also is shown in Table II.

Upon receipt at General Electric, 24.5 pounds of the potassium were transferred under argon pressure at approximately 225°F to a 25-pound capacity shipping container for ease in handling. Prior to transferring the potassium, the smaller shipping container, purchased from MSAR, was disassembled, cleaned, new bellows-sealed L-shaped valves installed, equipped with a liquid level probe, reassembled and helium leak checked. A sample of the potassium was taken during the transfer operation for chemical analysis, the results of which are given in Table II.

Most elements were below the detectable limits in both analyses and it will be impossible to detect any reduction in impurity levels as a result of the distillation operation; however, contamination due to the distillation and hot trapping may be detectable if it occurs. Also, it should be noted that the potassium was handled in stainless steel containers at both General Electric and the vendor plant.

TABLE II: CHEMICAL ANALYSES OF POTASSIUM (Container D-80)

Element	Chemical Analysis, ppm Vendor	GE
Oxygen[(1)]	11	19
Iron[(2)]	12	< 1
Boron	<10	-
Cobalt	< 5	< 1
Manganese	1	< 1
Aluminum	< 2	< 1
Magnesium	4	< 1
Tin	< 5	< 5
Copper	4	< 1
Lead	< 5	< 1
Chromium	< 5	< 1
Silicon	<25	< 1
Titanium	< 5	< 1
Nickel	< 5	1
Molybdenum	< 3	< 1
Vanadium	< 1	< 1
Beryllium	< 1	< 1
Silver	< 1	< 1
Zirconium	<10	< 5
Strontium	< 1	-
Barium	< 3	-
Calcium	11	1
Sodium	25	< 5
Columbium		< 1

(1) Oxygen analyzed using mercury amalgamation method.

(2) Metallic elements analyzed from KCl using spectrographic techniques.

IV. TEST FACILITIES

Potassium Purification

The construction and vacuum checkout of the entire purification system, including the transfer container, still, hot trap and helium purification system, were completed; the transfer container was filled with 24.5 pounds of potassium from shipping container No. D-80, and the potassium subsequently was outgassed for approximately 2 hours at 315°F to 450°F. The system will be moved into a ventilated enclosure and purification of the first batch of potassium is scheduled for completion the second week of May.

Corrosion

The fabrication of all major parts for the isothermal corrosion test facility, described in the Quarterly Progress Report No. 3, [Ref. 2], was completed. All drawings of the test facility were approved by the NASA technical manager on February 5, 1964. Figure 2 shows one of the molydenum susceptors, the upper and lower axial heat shields, the lower radial heat shields, the tantalum strip-heater assembly, the high-purity alumina thermocouple terminal-blocks positioned in the Type 304SS support table, and the Type 304SS heater-support table with molybdenum pins.

Twenty-four Cb-1Zr alloy capsules were machined and the bottom end caps TIG welded in place according to General Electric specification SPPS-3B, "Welding of Columbium-1% Zirconium by the Inert Gas Tungsten Arc" (See Figure 3). Six of these capsules were loaded with potassium as described in the Quarterly Progress Report No. 3 [Ref. 2] and sealed under vacuum by electron beam welding techniques. The six capsule welds were inspected by radiographic techniques and the capsules inserted in one of the molydenum susceptor blocks in preparation for the checkout tests. Subsequently, the susceptor and capsules were instrumented with Pt vs Pt+10%Rh thermocouples. Details of the instrumentation will be reported with the results of the checkout tests. At the end of this reporting period, the vacuum system was closed and the pressure was 6.2×10^{-8} torr as measured by a tubular Bayard-Alpert ionization gauge located on the test chamber.

Dimensional Stability

Fabrication of all major parts for the dimensional stability test facility, described in the Quarterly Progress Report No. 3 [Ref. 2], was completed. All drawings of the test facility were approved by the NASA technical manager on February 5, 1964.

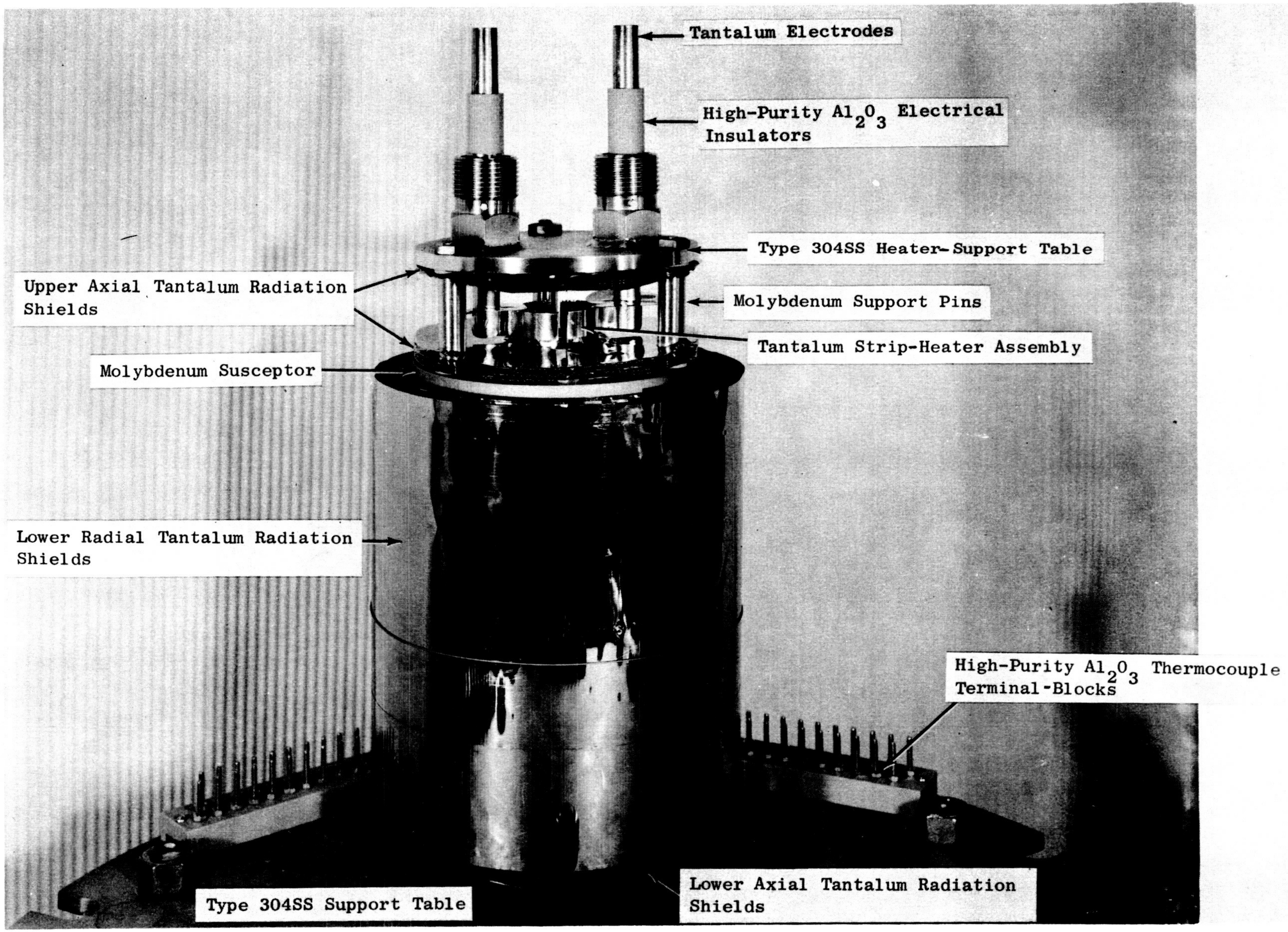


Figure 2. Isothermal Capsule Test Facility Showing the Molybdenum Susceptor, Lower Radial Heat Shield, Upper and Lower Axial Heat Shields, and Tantalum Strip-Heater Assembly in Place Before Upper Radial Heat Shields are Attached.

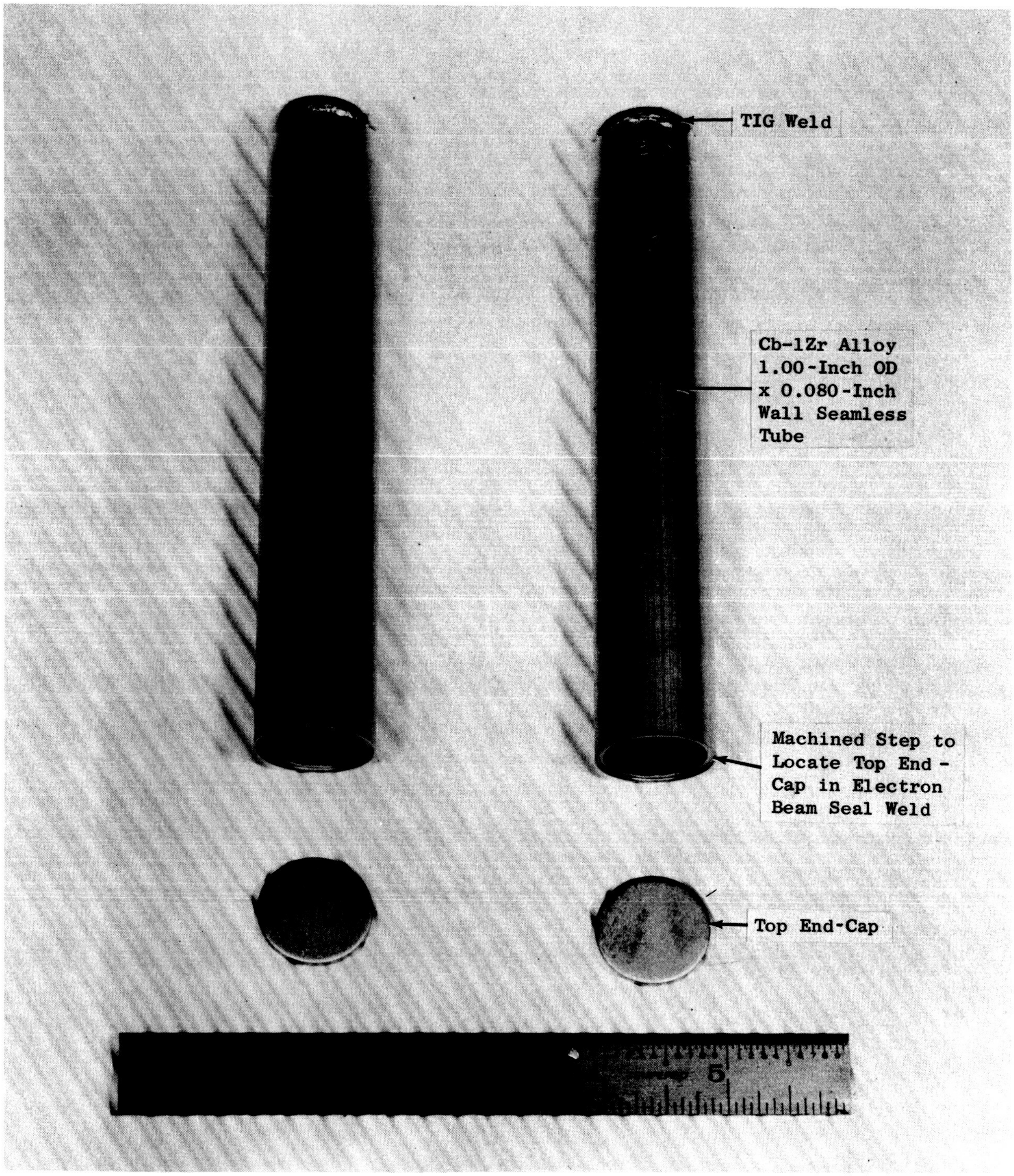


Figure 3. Machined and Cleaned Cb-1Zr Alloy Capsules After TIG Welding Bottom 0.080-Inch Thick End-Cap to 1-Inch OD x 0.080-Inch Thick Wall Seamless Tube. Note Electron Beam Weld-Prep on Top End of the Tube.

Thermal Expansion

Glass valves were fused to the two Chevenard dilatometer quartz specimen holders to enable the evacuation and back-filling of the tubes, providing an inert atmosphere for the thermal expansion tests. The delicate tripod mechanism that transmits the expansion of the sample to the recording chart was dismantled, thoroughly cleaned, reassembled and several routine test runs were made to ensure proper realignment of the mechanical linkage system. A trial run with a Cb-1Zr alloy specimen in the inert atmosphere will be made the first week in May.

Friction and Wear in Liquid Potassium

Several design changes were incorporated into the liquid potassium friction tester; the original configuration was shown in Figure 16 of Quarterly Progress Report No. 3 [Ref. 2]. These changes described in more detail in later sections of this report are listed below.

1) The thickness of the Inco 718 nonmagnetic diaphram between the magnets of the magnetic clutch was increased from 0.016-inch to 0.026-inch to provide a suitable safety factor in the event of accidential pressure loss on one side of the diaphragm.

2) The potassium sump heater, item 50, Figure 16 [Ref. 2], was changed from a stacked disc to a multiple fire-rod design.

3) Bakeout heaters and radiation shielding were added outside of the stainless steel shell which surrounds the Cb-1Zr alloy container.

4) A coiled-tube cooling channel was added to the outer surface of the shaft housing between the main bearings.

Critical Speed Calculations. Since shaft dimensions have been fixed, the critical speeds of the shaft were reanalyzed to be assured that the previous parametric studies [Ref. 1] were valid. The results are shown in Table III.

TABLE III: CRITICAL SHAFT SPEEDS FOR FRICTION AND WEAR TESTERS

Tester	Shaft Overhang Length, Inches	Dist. Between Bearings, Inches	Bearing Deflection, Inches/Lb.	Ncr, rpm	Ncr /4800 rpm
Vacuum(1)	11.70	8.00	1×10^{-6}	8200	1.71
Vacuum	11.70	8.00	5×10^{-6}	9400	1.96
Vacuum	11.70	8.00	1×10^{-6}	8150	1.70
Potassium	7.63	8.00	1×10^{-6}	9740	2.03

(1) Heat transfer interference holes at free end of shaft were considered.

The ratios of calculated Ncr to maximum operating speed of 4800 rpm are considered to be very satisfactory. It should be noted that the critical speeds reported in Table III are higher than those reported in Quarterly Progress Report No. 1, (Ref. 1), primarily because the latter values were based on an estimated design.

Stress Analysis of Nonmagnetic Diaphragm. Stress analysis of the nonmagnetic diaphragm between the two magnets of the magnetic clutch found the design of the diaphragm to be adequate for the planned pressure differential of 10 psi; however, for an accidentially imposed maximum pressure differential of 50 psi, the design is marginal. By increasing the minimum allowable diaphragm wall thickness from 0.016-inch to 0.026-inch and replacing the parabolic section of the diaphragm with an ellipsoid, the minimum safety factor of 1.68 was achieved at the inner surface, at the maximum diameter of the ellipsoid. Safety factors are based upon the following:

σ_{xi} = inner surface axial stress (psi)

= -28,830 psi

$\sigma_{\theta i}$ = inner surface circumferential stress (psi)

= 60,700 psi

σ_{ei} = inner surface effective stress (psi)

$$= \sqrt{\sigma_{xi}^2 + \sigma_{\theta i}^2 - \sigma_{xi}\,\sigma_{\theta i}}$$

= 79,160 psi

σ_a = maximum allowable stress (psi)

= .2% Y.S. of Inconel 718 at 400^{o}F

= 133,000 psi

$$F.S. = \frac{\sigma_a}{\sigma_{ei}} = \frac{133,000}{79,160} = 1.68 \text{ (based upon 0.2\% yield strength)}$$

The decreased normal deflections resulting from the redesign will allow the gap between the magnets to be decreased and allow the magnetic clutch to operate with greater efficiency.

Potassium Immersion Heater. The potassium immersion heater is one of the most critical components of the tester. Considerable effort was taken to resolve the existing design and identify a qualified vendor to fabricate the heating elements. The original design concept, i.e., single helically coiled, Cb-1Zr alloy sheathed, ceramic insulated heating elements, was not considered feasible by several experienced vendors. An alternate design, i.e., double stacked, Cb-1Zr alloy clad, ceramic insulated flat discs, is shown as item 50, Figure 16 [Ref. 2]. Quotations were requested from eight vendors of which only one agreed to attempt fabrication of the heater on a development basis and at considerable cost.

The Watlow Electric Manufacturing Company, St. Louis, Missouri, was visited and, from the ensuing discussions, it appears that their modified, standard fire-rod heater design, as shown in Figure 4, would be suitable for the intended application and also would be reasonable in cost. However, this design has not been approved by the NASA technical manager. Partial fabrication operations will be performed by the Watlow Electric Manufacturing Company, and others by the General Electric Company. The planned heater fabrication sequence (Refer to Figure 4) is as follows:

1) A Cb-1Zr alloy end plug (item 1) is welded (GE) to a 0.600-inch OD x 0.047-inch thick wall Cb-1Zr alloy tube (item 2).

2) A 5/8-inch OD Type 304SS tube (item 3) is welded (GE) to a Type 304SS vacuum flange (item 4) and to the Type 304SS side of a Type 304SS-to-Cb-1Zr alloy, bimetallic, tongue and groove brazed joint (GE) (item 5). A 3/4-inch OD x 0.049-inch thick wall Cb-1Zr alloy tube (item 6) is welded (GE) to the Cb-1Zr alloy side of the bimetal joint.

3) Two 3/16-inch diameter pure Ni power leads (item 8), which change to #10 pure Cu leads (item 9) in the vicinity of the bimetallic joint (item 5), are inserted (Watlow) in the 5/8-inch OD Type 304SS and

3/4-inch OD Cb-1Zr alloy tubes and MgO insulation is packed (Watlow) into the tube assembly. The insulation is further compacted where possible by swaging (Watlow). The bimetallic joint and Cu leads are above the liquid potassium pool, in a region considerably cooler than the 1600°F maximum temperature and are exposed only to the He-K vapor. The Ni wires (item 8) extend outside the bottom end of the vertical Cb-1Zr alloy tube (item 6) and are formed (Watlow) into circles capable of fitting inside the Cb-1Zr alloy torus (item 7).

4) Item 10, a nichrome heating element spirally wound over a solid BN (item 16) ceramic core, with pure Ni leads (item 11) protuding from one end,will be fabricated by Watlow. This element (item 10) is placed inside a 0.600-inch OD Cb-1Zr alloy tube (item 2) and vibro-packed with BN (item 16) insulation (Watlow). The assembly is compacted further by swaging (Watlow). About 3 inches of the 3.75-inch length of the element will be heated in operation.

5) A Cb-1Zr alloy torus (item 7) is formed, seven 1/2-inch diameter holes are drilled at 45° intervals into its upper surface, and the upper surface is cut through the holes (GE).

6) The heater wires (item 11) are welded (GE) to the Ni lead wires (item 8) at the proper spacing, after stringing solid Al_2O_3 beads (item 12) over the lead wires between the heater elements for insulation.

7) The upper surface of the torus (item 7) is opened, and the lead wires (item 8),with the heater element assemblies attached, are positioned (GE). Subsequently, the torus is sealed by TIG welds (GE) (item 13) and is joined to the 3/4-inch OD Cb-1Zr alloy vertical tube (item 6) by TIG welding (item 14) (GE).

8) An anti-vortex baffle (item 15) will be fabricated (GE) from Cb-1Zr alloy. To remove and replace the test specimens from the shaft of the tester, the baffle must be easily removed. This is accomplished by resting the baffle on the tops of two heater rods, 180° opposed.

The heater is designed for long service life at a power capacity of 10 KW; however, three heater assemblies will be fabricated to provide

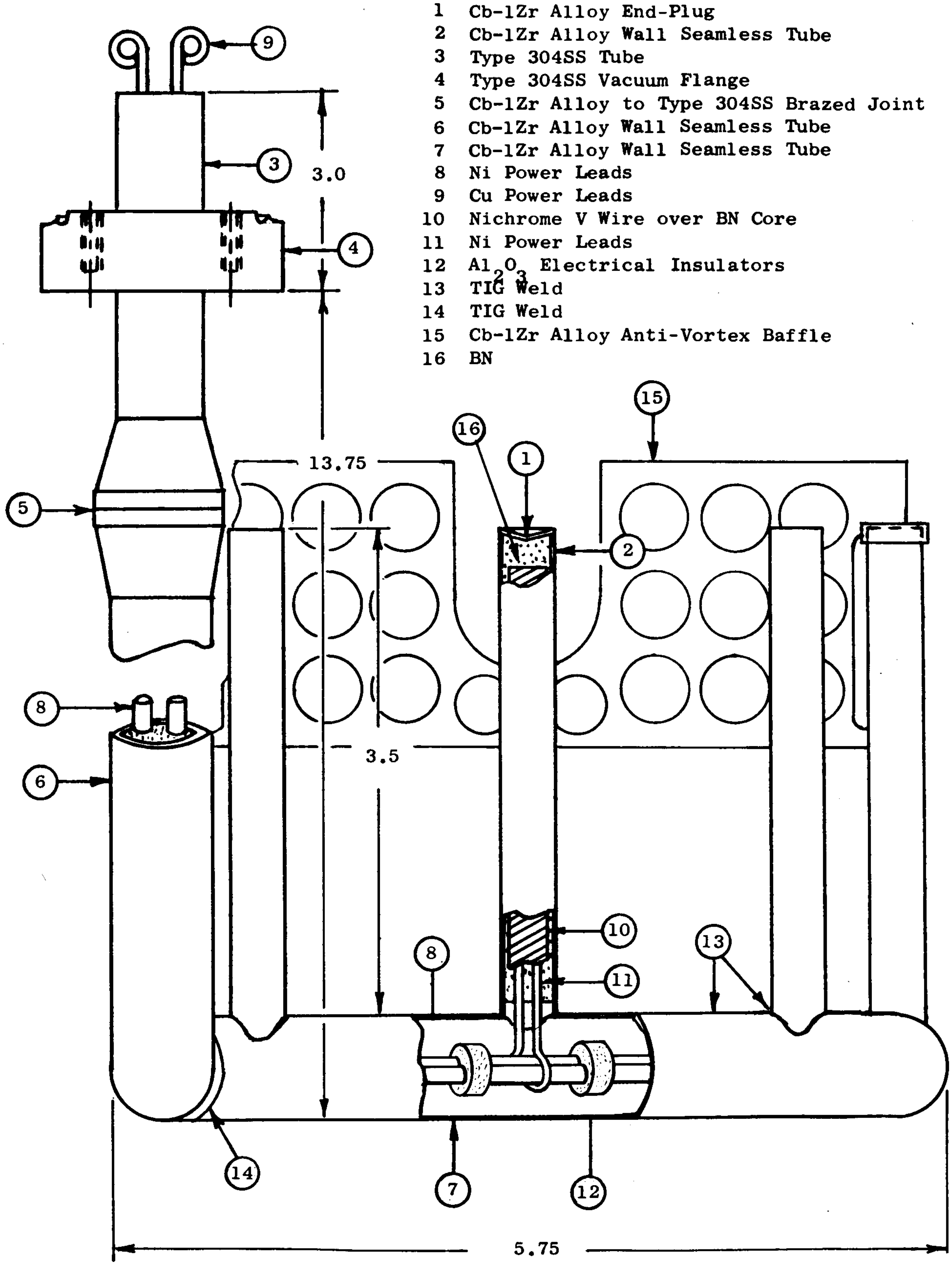


Figure 4. Potassium Immersion Heater (10 KW) for Friction and Wear Tester.

backup and prevent long facility downtime if trouble should occur. The heaters should withstand the planned 50 psi helium cover pressure, which is expected to suppress nucleation of potassium bubbles and prevent burnout of the heaters.

Bakeout Heater. Figure 5 shows a bakeout heater which will be brazed to the outer surface of the inner wall of the double wall, Type 304SS jacket that surrounds the Cb-1Zr alloy container. Two separate heater circuits will be incorporated for reliability, since the double wall stainless steel jacket will be welded together and evacuated, making replacement a major problem. Each heater element will be about 75-feet long and consists of a single Nichrome heater element surrounded by ceramic insulation and a 1/8-inch OD stainless steel sheath. One circuit will enter the evacuated stainless steel jacket through a vacuum feed-through, spiral around a fourth of the bottom surface area, spiral to the top of the chamber at a lead of two wires/inch in the region of the potassium sump, turn 180° at the top of the chamber, spiral downward between the wires going up, spiral around a fourth of the bottom surface area, and exit through the vacuum feed-through. The second circuit will fill the spaces between the wires of the first circuit.

The heater raises the temperature of the inner stainless steel wall to 500° to 700°F and will evaporate the residual potassium from the sump and also in the space between the Cb-1Zr alloy container and the inner surface of the stainless steel jacket. The conductance of the flow path involved was calculated and is believed to be satisfactory. Preliminary vendor contacts have verified the feasibility of the design and have indicated that the 700°F temperature can be achieved.

Heater efficiency will be improved by the installation of crimped-foil radiation shields, positioned adjacent to the inner wall of the outer stainless steel jacket.

Cooling Channels. Cooling channels were designed with calculations based on a heat removal capacity of 5 KW for each channel, exceeding expected requirements (Figure 6). The channels were added to the outer surface of the shaft housing and performance checked for cooling capacity and pressure losses, using Dowtherm A as the coolant. The calculated pressure losses are listed below:

Channel	Pressure Loss, psi	T_{in}, °F	T_{out}, °F
A	2.7	100	200
B	4.7	100	200
C	0.2	100	200
D	0.1	100	200

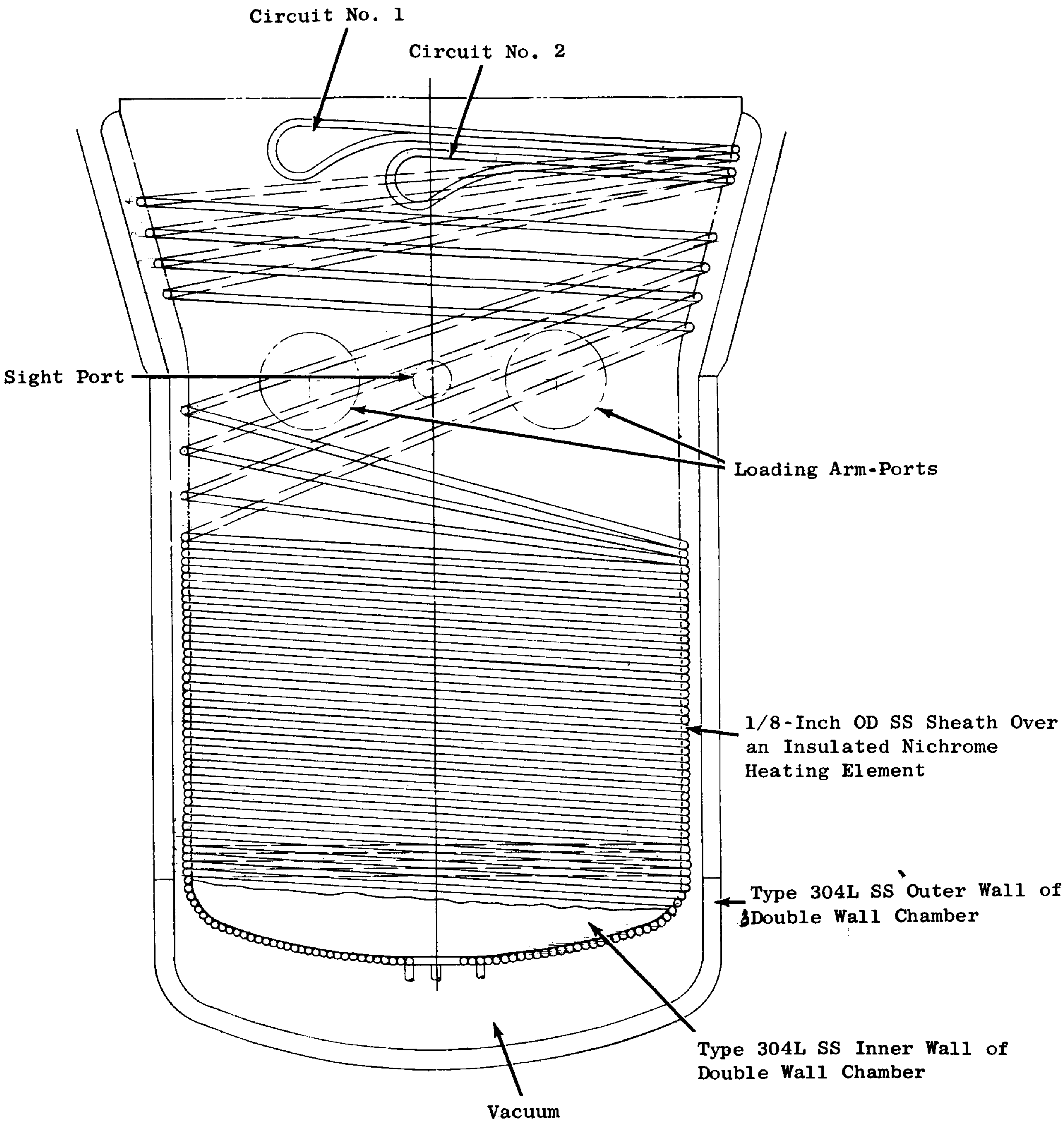


Figure 5. Location of Bakeout Heater Coils on Friction and Wear Tester.

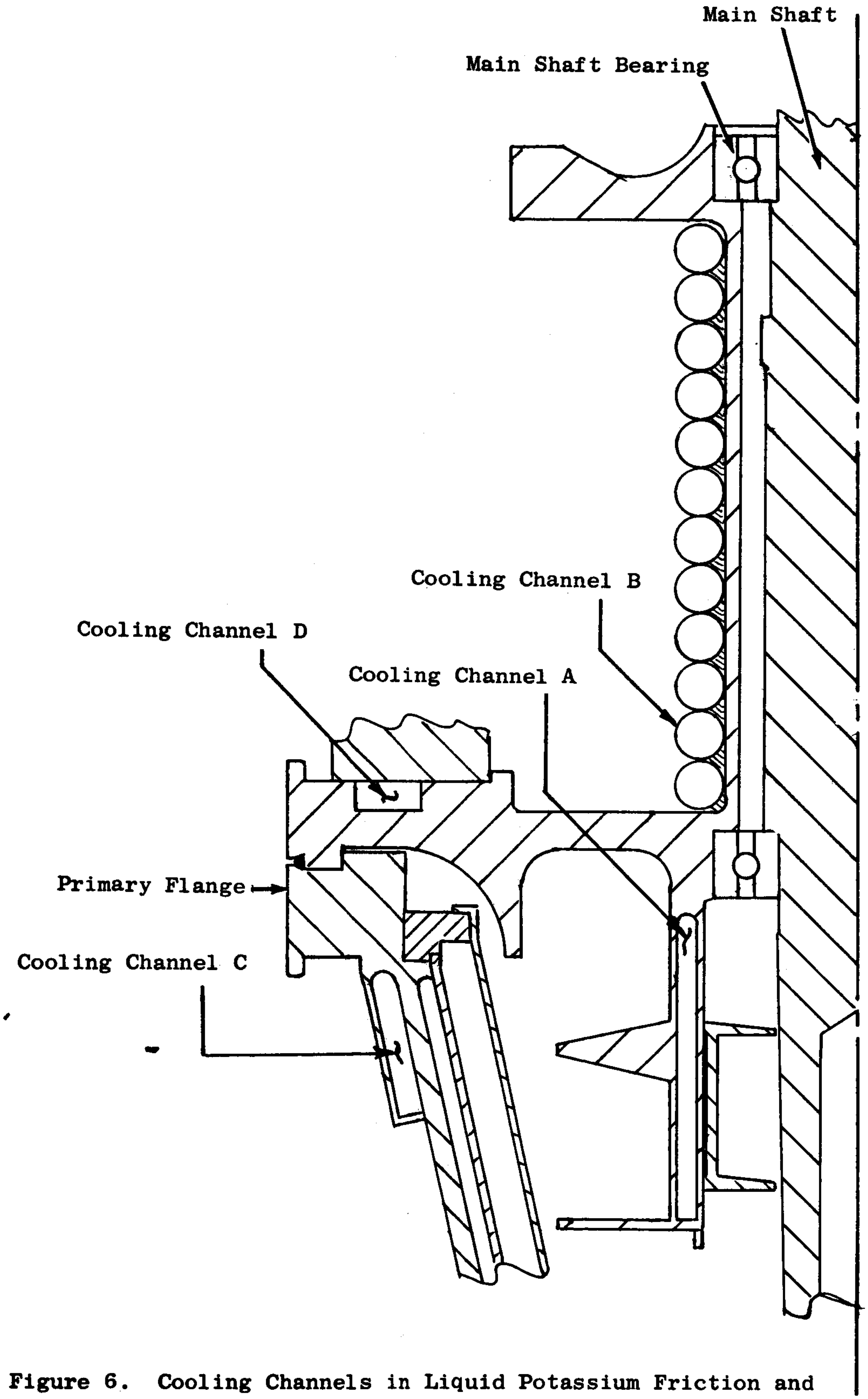


Figure 6. Cooling Channels in Liquid Potassium Friction and Wear Tester.

Channel A was baffled to provide twelve axial passes of the fluid through the channel volume.

Dowtherm A boils at 500°F and cokes at 750°F, and therefore, does not allow these same channels to be used very efficiently for heating during evacuation of the tester or evaporation of the potassium.

The use of a dense oil which would withstand temperatures above 750°F and electrically heated air are being considered. However, such oils become very viscous at the cooling temperatures desired and the pressure drops increase by several orders of magnitude. The comparative merits of both of these approaches must be evaluated in more detail.

An additional thin cooling channel, which surrounds the outside of the tester in the plane of the loading arms, is designed to protect the load arm bearings from lubricant evaporation during operation.

Heat Transfer Analysis. A heat transfer analysis of the final design of the internal tester components was initiated to prove the effectiveness of the cooling channels in maintaining acceptable main shaft bearing temperatures. Results may very well be limited to a parametric study, since the computor program, being used, is limited in its ability to allow for radiation.

Drive Motor. A 5 HP silicon-controlled-rectifier electric motor was ordered. The motor provides for 1% speed regulation, constant torque from 50-2500 rpm (100-5000 rpm at the tester shaft with a 2:1 ratio belt drive), current-limited acceleration control, nonreversing rotation and dynamic braking.

The acceleration response time of the components attached to the driven magnet was calculated to be sufficiently fast to prevent overspeed of the driving magnet. This is important, since a small relative speed differential between the magnets results in demagnetization of the magnets and subsequent facility shutdown for component replacement.

Test Facility. The friction and wear tester and the associated facility for testing with liquid potassium will be installed in an isolated, air-conditioned, laboratory area connected to a 9000 CFM fume scrubber system. A schematic of this installation is shown in Figure 7 and a layout of the facility is shown in Figure 8. Supporting facilities for the test rig consist of the following:

1) Potassium and inert gas purification.

2) Auxiliary heating and cooling equipment.

3) Environment chamber for enclosing the tester.

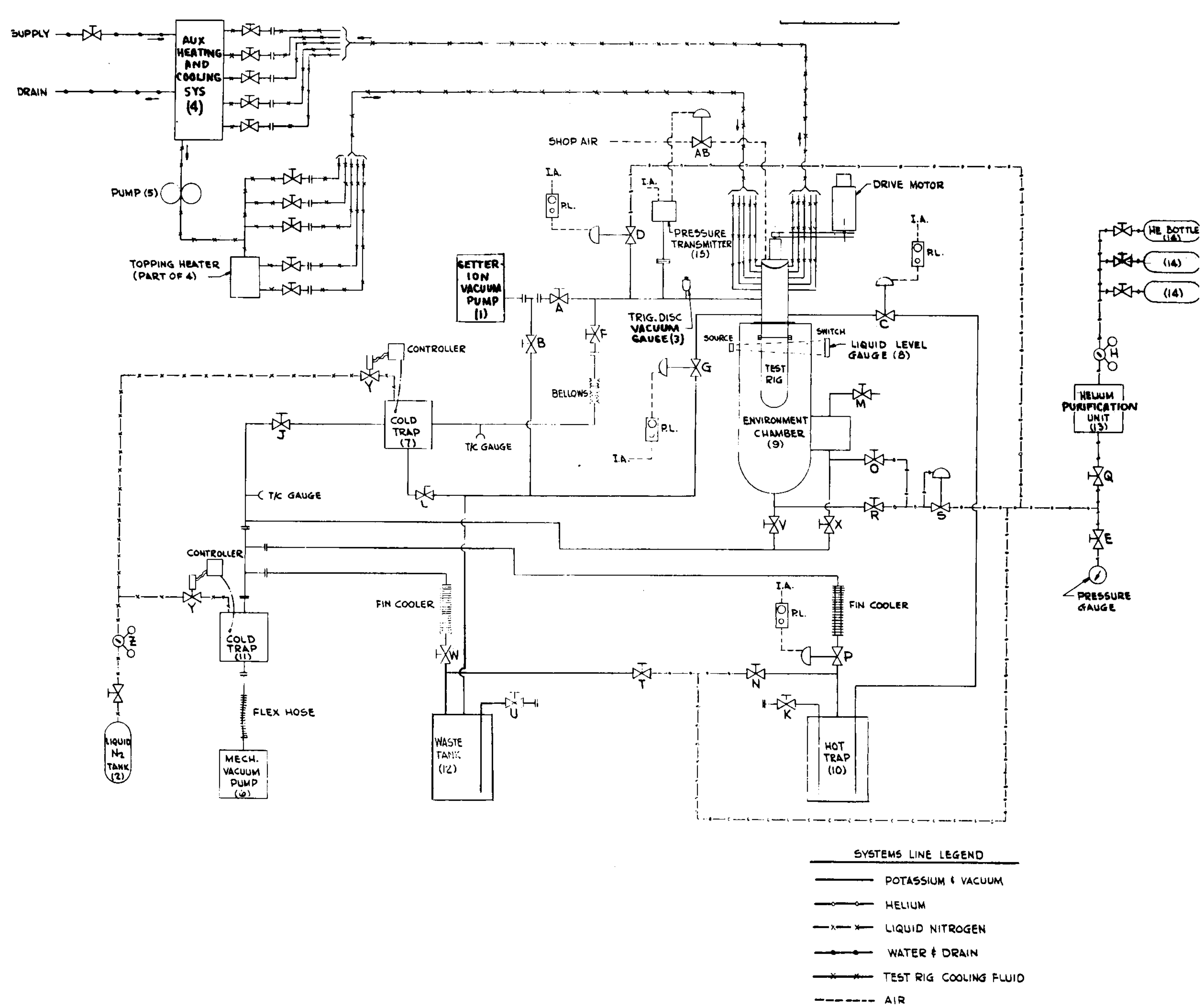
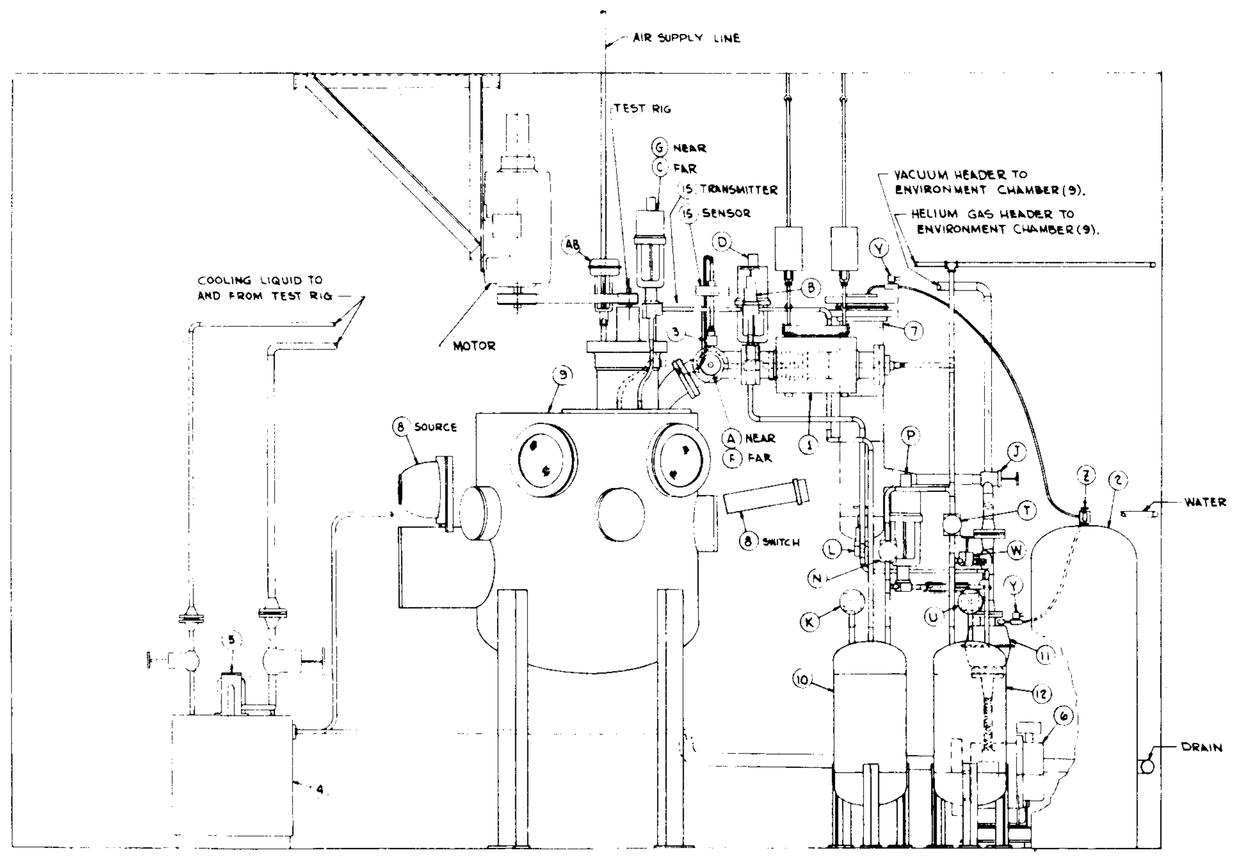


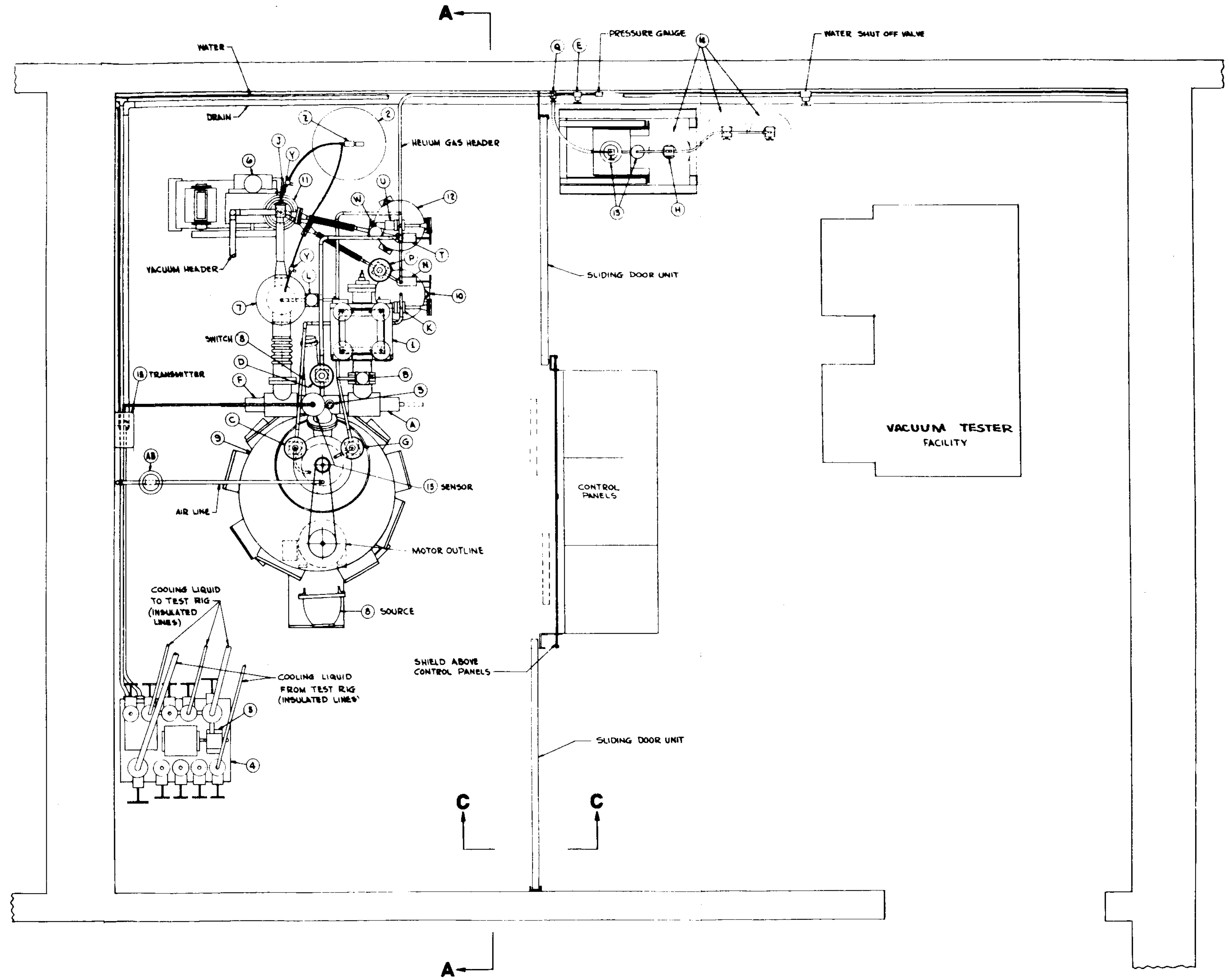
Figure 7. Schematic of Test Facility Requirements for Liquid Potassium Friction and Wear Tester.

COMPONENT DESCRIPTION

ITEM	NAME
1	GETTER-ION VAC. PUMP
2	LIQUID NITROGEN TANK
3	TRIGGERED DISCHARGE GAUGE
4	AUXUARY HEATING & COOLING SYS.
5	COOLING SYSTEM PUMP
6	MECHANICAL VACUUM PUMP
7	COLD TRAP
8	LIQUID LEVEL GAUGE
9	ENVIRONMENT CHAMBER
10	HOT TRAP
11	COLD TRAP
12	WASTE TANK
13	HELIUM PURIFICATION UNIT
14	HELIUM BOTTLES
15	PRESSURE INDICATOR



SECTION A-A
SCALE 1/4"=1'-0"



PLAN OF LAB AREA B
SCALE 1/8"=1'-0"

Figure 8. Layout Drawing of Liquid Potassium Friction and Wear Tester and Test Facilities.

4) Facility for transferring potassium to and from the tester.

5) Liquid level measurement.

6) Safety.

1) Potassium and Inert Gas Purification.

High-purity grade potassium will be purchased and purified according to procedures described in detail in Quarterly Progress Report No. 2 (Ref. 3) and delivered to the test area for charging into the 25-pound capacity hot trap, permanently attached to the test rig. After transfer, the potassium will be repurified for approximately 50 hours at 1400°F.

The helium gas, used for the environment chamber and as cover gas for the tester, will be purified continuously as described previously in Quarterly Progress Report No. 2 (Ref. 3). The inert gas supply and purification system is shown as items 13 and 14 of Figure 8.

2) Auxiliary Heating and Cooling Equipment.

A heat exchanger (items 4 and 5 of Figure 8) will be mounted in the test area near the friction tester to provide cooling fluid for the tester flanges, bearings and pivot arm mounts and heating fluid for bakeout of the tester during outgassing and evacuation. The auxiliary heater and cooler capacity controls are covered in General Electric Specification SP-FS11, "Auxiliary Heating and Cooling System", The circulating fluid is a high temperature polphenyl ether with a low vapor pressure and high auto-ignition temperature.

3) Environment Chamber.

The environment chamber (item 9 of Figure 8) encloses the removable bottom portion of the friction tester and consists of 4 sight glasses, 5 glove ports, vacuum interlock loading-chamber, tester flange and support fixture.

The inert atmosphere chamber is attached to the test rig by means of a standard grooved, rubber O-ring vacuum flange. This arrangement permits the disassembly of the lower half of the tester and the removal and installation of test specimens within a protective atmosphere.

Within the chamber, provision is made for the support of the Cb-1Zr alloy container and surrounding stainless steel jacket while the specimens are being changed. Also, space is provided to store extra loading arm assemblies and for load arm recalibration between runs. Vacuum feed-throughs for electrical power, coolant instrumentation, etc., are located in the chamber walls. General Electric Specification No. SP-FS10, "Inert Atmosphere Chamber", lists additional details of the chamber.

4) Facility for Transferring Potassium to and from the Tester.

Layout of the facility in the test area, the sizes of the various components, and the type and sizes of the valves and pumps are shown in Figure 8.

Operation of the transfer facility, shown in Figure 7, is summarized in the following paragraphs:

4.1 The hot trap, item 10 of Figure 7, is evacuated, outgassed and charged with purified potassium through valve K. The filling can be accomplished by decreasing the pressure in the hot trap through valve P or by pressurizing the potassium into the trap. With all valves to the hot trap closed, the potassium is purified for approximately 50 hours at a temperature of $1400^{\circ}F$ in the facility hot trap.

4.2 The friction tester is evacuated to 10^{-9} torr. Initial pumping is accomplished with a liquid nitrogen, cold-trapped mechanical vacuum pump, item 6 of Figure 7, through valves J and F. At a pressure of 1 to 5 x 10^{-3} torr, valve F is closed, valve A is opened and the high vacuum is achieved by means of a getter-ion pump, item 1. It is estimated that a 150 ℓ/sec pumping speed will be adequate to achieve the 10^{-} torr vacuum in a 15-hour period. The lines from the getter-ion pump to the friction tester will be line-traced with electric heaters and the friction tester will be heated with the auxiliary heater, item 4, to provide a temperature of $750^{\circ}F$ for outgassing.

4.3 Pressure in the friction tester is increased to ambient pressure with high purity helium through valve D, after closing valve A, and the Cb-1Zr alloy container in the test rig is filled with approximately 7.5 pounds of the hot trapped potassium by pressurizing the hot trap through valve N and opening valve C.

4.4 With the proper cover-gas pressure applied through valve D, the environment chamber, item 9, at a slightly positive inert-gas pressure, the liquid level gauge in operation , item 8 (see Paragraph 5), and valve C closed, the friction tests may be conducted. During the friction tests, the auxiliary heating and cooling system will be switched to the cooling cycle to cool the bearings and flanges. The Taylor pressure transmitter, item 15, will monitor the pressure in the friction tester and control the air pressure on the concave side of the metal diaphragm on top of the test rig. Air pressure will track the helium pressure inside the friction tester and prevent high stresses from occurring in the metal diaphragm during the high pressure operation.

4.5 At the conclusion of the friction test, valve G will be opened and the bulk of the potassium dumped into the waste tank, item 12. The friction tester may be flushed with additional potassium from the hot trap and dumped into the waste tank by pressurizing through valve D. The auxiliary heating and cooling system will be switched to heating to prevent freezing of the potassium in the tester.

4.6 The friction tester will contain some residual potassium which must be removed. This will be accomplished by distilling the potassium by applying heat with the line heaters, auxiliary heating fluid, and bakeout heaters in the friction tester and evacuating the tester with the mechanical pump through the cold traps, items 11 and 7, and valves J and F. The combination of heat, mechanical and cryopumping should vaporize a pound of potassium in less than 24 hours.

4.7 After all the potassium has been vaporized from the test rig and has been condensed on to the cold trap, item 7, valve F is closed, valve A is opened and the system pumped to a pressure of 10^{-9} torr.

4.8 The pressure is increased to ambient pressure with purified helium by opening valve D, the tester is disassembled and new specimens are installed in the friction tester by working through the environment chamber.

4.9 The potassium on the cold trap, item 7, is melted by heating the trap and is dumped in the waste tank, item 12, with valves F and J closed and valve L open. The potassium is removed from the waste tank through valve U by pressurizing the tank through valve T.

4.10 Since the hot trap will hold several charges of potassium for the tester, it will be possible to conduct the second test starting with the procedure of paragraph of 4.2.

5) Liquid Level Measurement.

The liquid level of the potassium in the friction tester will be measured with an Ohmart Model GMP gauge (item 8 of Figure 8). This method of measurement operates on the principle of absorption of gamma radiation by the potassium. The system consists of a gamma source collineated to pass its ray through the environment chamber and friction tester with a counter to pick up the resulting rays and convert them to an electrical readout. The quoted accuracy for the proposed system is ± 1/8 inch with a time constant of 1 1/2 minutes. System precalibration with a fluid, having a absorptivity equal to that of potassium, will improve the accuracy of the measurement.

6) Safety.

Figure 8 shows the overall test facility and friction tester bounded on three sides by the masonry walls of the test area and on the fourth side by a series of instrument control panels and two sliding doors which will be closed during all high pressure testing operations. As mentioned previously, the test area is connected to a scrubber system to collect fumes in the event of potassium leakage.

Four high-pressure system control valves will be remotely operated from the instrument control panel (Figure 8). Valve D will increase the inert gas cover pressure in the friction tester; valve C will increase the liquid level in the friction tester; valve G will decrease the liquid level in the friction tester; valve P will decrease the pressure in the hot trap and in conjunction with valve C, decrease the inert gas pressure in the friction tester.

Instrumentation. The friction and wear test rig requires instrumentation for these measurements:

1) Temperature of the test section, bearings, flange, chamber walls, coolant.

2) Pressure in the test chamber.

3) Spindle speed.

4) Vibration.

5) Test specimen load.

6) Torque caused by friction between the test specimens.

1) Temperature.

Two 0.125-inch OD x 0.32-inch thick wall thermocouple wells will be located on the loading arm, as shown in Figure 9. They will be attached to the arm by brazing to the type 304L SS arm through the integral flange penetrating into the environmental chamber and by strapping to the TZM arm with tantalum straps. Since strapping the wells tightly against the test specimen will assure good temperature readings, this system of temperatures measurement is expected to be very reliable. It is expected that the use of thermocouple wells and replaceable thermocouples (chromel-alumel wires sheathed in 0.040-inch OD Inconel tubes) will prevent excessive downtime of the test rig for thermocouple replacement, which would likely be required if swaged, tantalum-sheathed thermocouples were bonded directly to the TZM arm. The present design required a minimum number of vacuum-tight weld or braze seals. The sequence of fabrication provides that the well brazes be made before the bellows are welded to the flange so that the bellows will not be subjected to the high temperatures of the brazing cycle.

The potassium sump temperature will be monitored by a chromel-alumel thermocouple as shown in Figure 10. This method was chosen to minimize the number of vacuum feed-throughs, simplify fabrication by eliminating a Cb-1Zr alloy-to-stainless steel joint and to facilitate rapid thermocouple replacement without shutdown of the tester. During assembly of the components, the Cb-1Zr alloy container will be forced downward to assure positive contact of its bottom surface with the thermocouple well.

Two chromel-alumel thermocouples will be positioned in the stainless steel wall of the tester and penetrate almost to the races of each main shaft bearing.

Three chromel-alumel thermocouples will be located around the main flange, joining the tester and the inert atmosphere chamber at 120^{o} intervals. The thermocouples will be located on the free side of the flange, and will not require access holes through

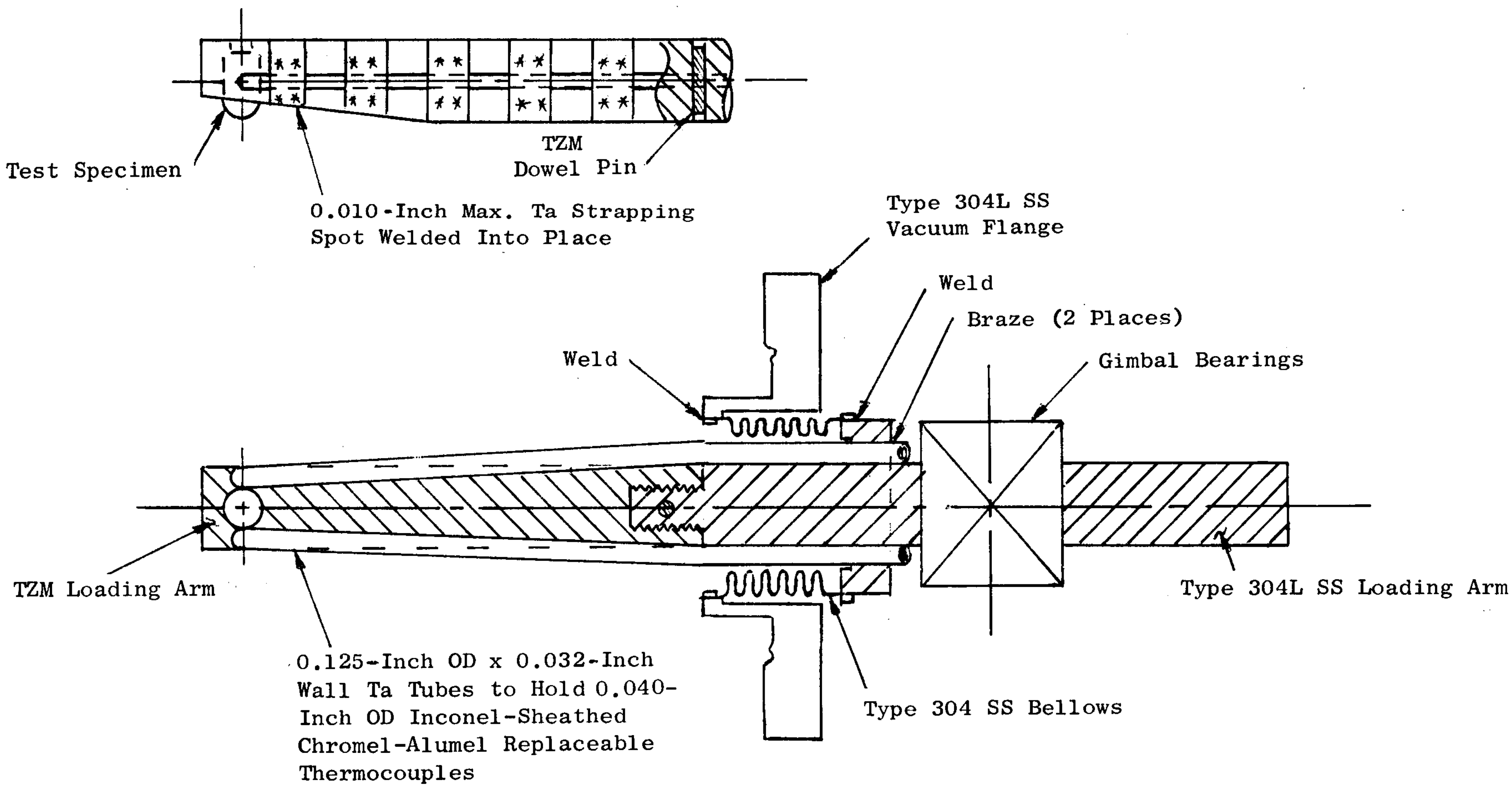


Figure 9. Location of Thermocouples in Loading Arm of Liquid Potassium Friction and Wear Tester.

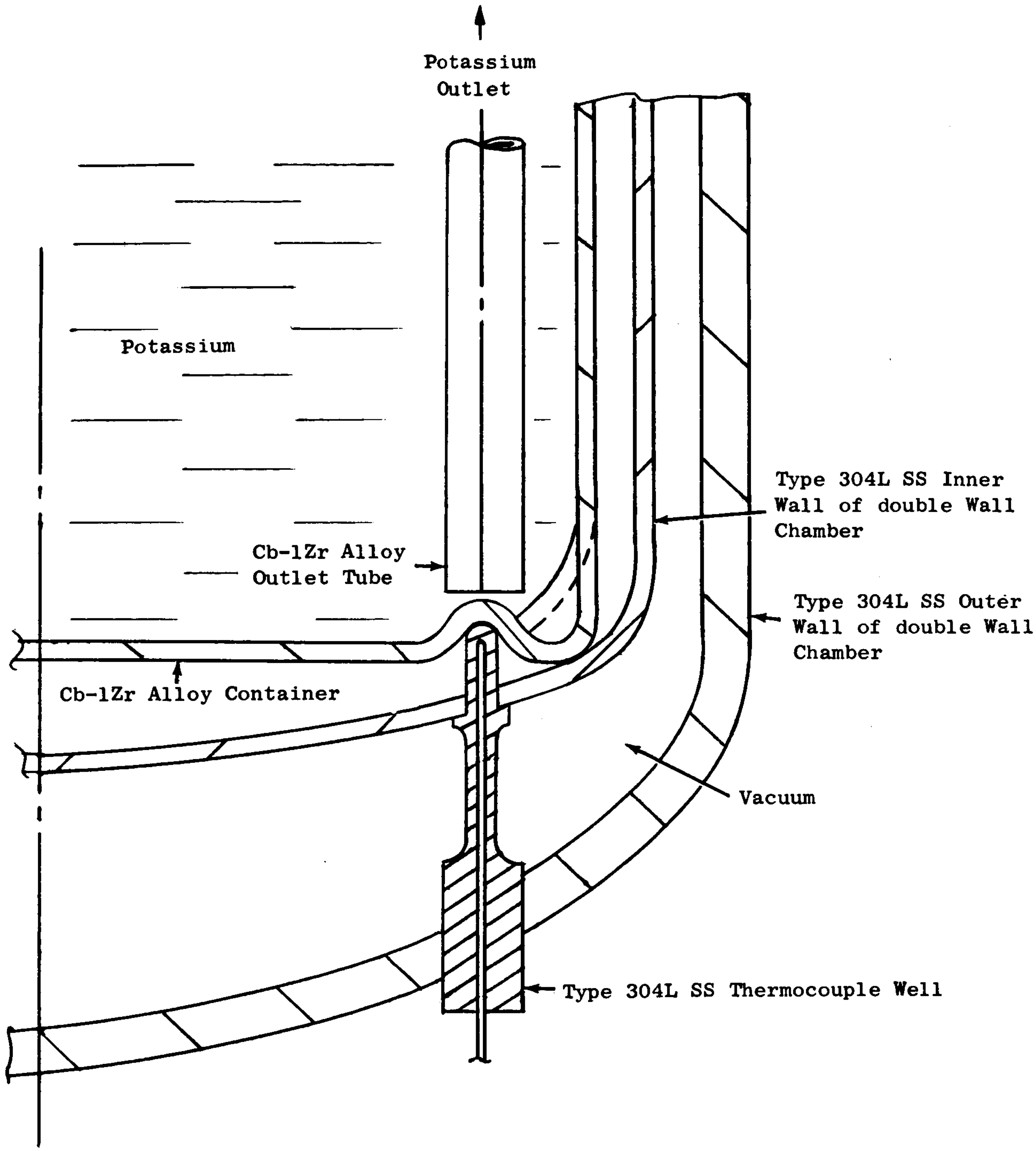


Figure 10. Location of Thermocouple to Measure Temperature of Potassium in Sump.

either the tester or the inert atmosphere chamber walls.

Two chromel-alumel thermocouples will be located in wells at the entrance and exit lines of the coolant, providing inlet temperature control as well as a means of estimating the amount of heating or cooling being accomplished during operation.

Two chromel-alumel thermocouples will be located on the Inconel 718 membrane, a short distance from the magnets, to monitor the temperature of the membrane when the magnets are transmitting power. This assures that the membrane is capable of withstanding the imposed pressure load, and also gives a rough approximation of the temperature of other components at the upper end of the chamber.

Four chromel-alumel thermocouples will be located on the outer wall of the friction tester and one chromel-alumel thermocouple will be located at the getter-ion pump to monitor and control the bakeout.

2) Pressure.

Since loss of helium pressure during $1600^{o}F$ potassium operation will cause immediate and violent boiling of the potassium, resulting in burn-out of the potassium heater, the power supply to the potassium sump heater will be automatically disrupted if a loss of helium pressure should occur.

Pressure gauges will be used on both the helium cover-gas system and the air back-pressure system (backing the Inconel 718 membrane). The helium pressure will provide a signal which will actuate the air pressure valve to maintain equal pressures for membrane protection.

Vacuum will be measured by General Electric trigger discharge gauge Model No. 22GT214.

3) Speed.

An electro-magnetic, high-voltage, pickup, Model 3045, manufactured by the Electro Products Laboratories, will measure shaft speed. This device is positioned in the wall of the shaft housing close to the shaft and for pickup uses the passage of each of twenty teeth machined into a Type 410SS sleeve over the shaft. No access holes are required through either the friction tester or the inert atmosphere chamber walls.

4) Vibration.

Vibration will be measured at two locations, 90^{o} apart, at each set of main bearings. The pickups will not penetrate either the tester or the inert atmosphere chamber walls.

5) Test Specimen Load.

The normal load applied on the test specimens will be imposed by dead weights. Calibration of the pertinent tare weight involved is planned by having a calibration stand inside the inert atmosphere chamber. The calibration procedure is described briefly in Quarterly Progress Report No. 1 [Ref. 1]. Provisions will be made for pressurization of the loading arm bellows during calibration.

6) Torque.

A ring type load cell with four strain gauges mounted internally to form a bridge will measure frictional torque. Wiancko Force Pickups, F1021, were selected and will have a range of 0.2 to 20 lbs. with an accuracy of ± 0.1%. Calibration of the force pickups is described in Quarterly Progress Report No. 1 [Ref. 1].

V. FUTURE PLANS

The summary which follows enumerates the steps to be pursued during the succeeding quarter to implement this study.

1) Complete receipt of corrosion and dimensional stability test specimens; order and receive hot hardness, thermal expansion and compression test specimens for the 14 candidate materials.

2) Complete checkout of the potassium purification system and purify potassium for first corrosion test run.

3) Complete checkout run of corrosion test facility and initiate testing of 6 materials at the three test temperatures.

4) Setup and conduct checkout run for the dimensional stability test facility and initiate specimen testing at two test temperatures.

5) Complete checkout tests on the hot hardness, thermal expansion and compression facilities and initiate testing.

6) Complete all detail drawings and associated specifications for the liquid potassium friction and wear test rig and forward inquiries to vendors for quotations.

7) Complete heat transfer analysis for liquid potassium friction and wear tester.

8) Prepare installation and operation procedures for the liquid potassium facility and tester and formulate preliminary test plans.

REFERENCES

[1] "Materials for Potassium Lubricated Journal Bearings," Qtr. Rept. 1, Ctr. NAS 3-2534 (July 22, 1963), SPPS, MSD, General Electric Company.

[2] "Materials for Potassium Lubricated Journal Bearings," Qtr. Rept. 3, Ctr. NAS 3-2534 (January 22, 1964, SPPS, MSD, General Electric Company.

[3] "Materials for Potassium Lubricated Journal Bearings," Qtr. Rept. 2, Ctr. NAS 3-2534 (October 22, 1963), SPPS, MSD, General Electric Company.